LCLS-II Prototype Cryomodule Testing at Fermilab

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Project Background

LCLS-II is a next generation x-ray free electron laser to be constructed at SLAC. Fermilab is responsible for assembling and testing seventeen 1.3 GHz and two 3.9 GHz cryomodules. The first 1.3 GHz prototype cryomodule, consisting of eight nine-cell superconducting cavities, was sent to Fermilab's Cryomodule Testing Facility (CMTF) on July 20, 2016 for testing. We analyze the performance of facility's RF system, as well as develop graphical interfaces to monitor the test.

Figure 1. Superconducting cavity at Fermilab's Technical Division.

Cryomodule Testing Facility

Fermilab's Cryomodule Testing Facility (CMTF) has two test stands that could be cooled down to 2 Kelvin [1]. The first test stand, CMTS1, hosts the testing for LCLS-II cryomodules.

Figure 2. 1.3 GHz Prototype cryomodule in CMTS1.

Purposes of Testing

The tests aim to characterize both the cryomodule's and each cavity's performance to ensure they meet the stringent minimum acceptance criteria, including:

- usable gradient, E_{acc} (MV/m)
- intrinsic quality factor, Q_0
- magnetic effect and shielding
- tuner and piezo range test

To assure as accurate a calibration as possible, the gradient, E_{acc}, will be calculated from two separate methods [2]:

1. $E_{acc} = \sqrt{P_{probe} Q_2 \frac{(r/Q)}{L}}$
2. $E_{acc} = \sqrt{4\, P_{forward} Q_0 \frac{(r/Q)}{L}}$

Since both methods depend on the power measurements, we characterize the power system to determine their accuracy.

RF System Analysis

Figure 3. Layout of RF system at CMTS1.

CMTS-1 has eight 4 kW solid state amplifiers (SSA), one for each cavity. Power attenuations through the waveguides are calculated [3]:

- Straights: (dBm/m) $\alpha_c = 8.686 \frac{R_s}{\eta b} \frac{(1 + (2b/a)(\omega_c^2/\omega^2))}{\sqrt{1 - \omega_c^2/\omega^2}}$
- Bends: Power loss = 0.01%
- Couplers → Main arm power loss = 0.01%
  → Side arm power loss = 0.06%

- SSA #1, 3, 5, 7 --- Calculated total loss = 2.37%
- SSA #2, 4, 6, 8 --- Calculated total loss = 2.22%

Table 1. Comparison of calculated power loss and measured power loss from the test runs for five SSAs. SSA #3, 5, 6, and 7 still need complete calibration.

SSA #	2	3	5	6	7
SSA Output (W)	668.1	2195	2107	1539	1055
Calculated Loss (W)	14.9	52.0	49.9	34.2	25.0
Measured Loss (W)	14.8	132	166	119	64.7

SSA Performance Analysis

Data from the test runs are obtained at 1Hz. The output is stable with RMS less than 2% during continuous operation up to two days duration. The longer run (>10 hrs) exhibits parasitic oscillations with a period of around 0.8 hour.

Table 2. SSA output statistics. Parasitic oscillation is calculated by Lomb-Scargle algorithm implemented in VARTOOLS [4, 5 ,6].

SSA #	2	3	5	6	7
Duration (Hrs)	49.75	1.5	0.6	16	14.75
RMS (%)	2.08	0.28	0.15	0.36	0.50
Period (Hrs)	0.79	-	-	0.79	0.78

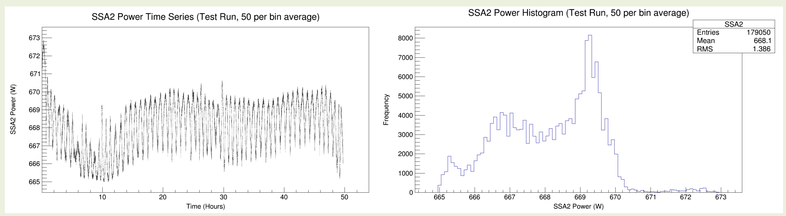

Figure 4. Time series [left] and histogram [right] of the output from SSA #2 during a test run. Resolution of the outputs are increased by using binning average with 50 data points per bin.

Interfaces Development

During testing, data will be acquired through Fermilab's Accelerator Control System (ACNET) at rates up to 10 kHz. We develop graphical interfaces to display real-time data, such as powers, temperatures, and magnetic fields using a Fermilab-developed synoptic display platform.

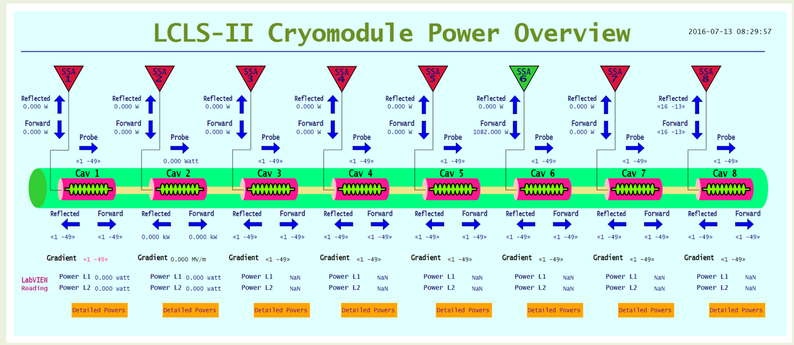

Figure 5. Synoptic display of different power readouts. SSA status is shown as On (green) or Off (red). Clicking "Detailed powers" will link to powers display for individual cavity with time plot.

Conclusions & Future Plans

- Calculated and measured losses through the waveguides match for SSA #2. Complete calibrations are needed for SSA #3, 5, 6, and 7.
- Power output from SSA is stable up to two days with RMS less than 2%, which contributes only 1-2% error to gradient calculations.
- Necessary graphical interfaces to monitor the test were developed.
- Testing of the prototype will last until late 2016. Production cryomodules will be tested on a 28-day cycle beginning in 2017.

References

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